Computer Assisted Photovoltaic Cells Project

Extended Abstract

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ABSTRACT

A computational tool based on the Finite Element Analysis technique, as well as in multiphysical models, was used to simulate the process of manufacturing and characterizing of photovoltaic cells. Nine cell types have been studied which use as substrate the suitably doped monocrystalline silicon. The anti-reflective layers of the cells were obtained by the deposition of thin films of silicon dioxide (SiO_2), titanium dioxide (TiO_2) and silicon nitride (Si_3N_4). The upper electrode of the cells was initially composed of aluminum film and was subsequently replaced by transparent conductive oxide films (TCO), more specifically indium tin oxide (ITO) and zinc oxide (ZNO). The electrical characteristics and Figures of Merit of the cells were obtained and analyzed to compare the performance of the simulated cells using different anti-reflective and conductive materials.

PHOTOVOLTAIC CELLS CONCEPTS

• **Semiconductors theory → Photoeletric and Photovoltaic effects**; The PN junction; • **Photovoltaic Cells parameters → Materials of antireflective layer; Materials of eletrode**

ADDITIONAL KEYWORDS AND PHRASES

ACM proceedings, text tagging

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1 INTRODUCTION

Currently, in Brazil, serious investments have been made in relation to the production of electricity through hydroelectric plants, which, despite providing significant amounts of electricity to the country, present great disadvantages related to the damages caused to the country, related with where they are installed, as well as the costs of their maintenance [1]. Considering that the country has an intense solar energy potential, it is questionable, at the present time, the low coverage of investments in photovoltaic solar energy, which is limited to discrete projects spread throughout the country. It is a clean energy (this implies in its behavior as renewable energy for not emitting pollutants in the atmosphere) that has several favorable aspects, such as ease of maintenance and profitability. For these reasons, photovoltaic modules are presented as an excellent alternative to be applied in the country, even if complementary to hydroelectric power [2]. For these reasons, this project has as main objectives: to do a study about the characteristics and factors responsible for affecting the behavior and performance of photovoltaic cells, including their production process; Design and analyze them using a CAD (Computer Aided Design) tool, aspire to contribute to the better development of future photovoltaic cells, and to stimulate studies on the actual production of photovoltaic modules, enabling the production of cells with more advantageous characteristics (Cost-benefit ratio well associated).

2 EXPERIMENTAL AND COMPUTATIONAL DETAILS

2.1 Photovoltaic cells manufaturing

Nine cells were manufactured using a Computer Aided Design (CAD) tool from SILVACO, through Finite Element Analysis (FEA), as well as using multiphysical parameters and models. Next, photovoltaic cells were designed using always the monocrystalline silicon as substrate, modifying the materials used in the anti-reflective layer, and the electrodes. Using one of the developed cell designs, the influence of external effects (temperature and irradiance) on cell performance was analyzed. Through the simulations, the values of the Figures of Merit were also verified and compared, as well as the I-V curves of the projected cells, by means of graphs and numerical results. The Figures of Merit studied in this cells was: The I-V characteristics – Maximum Power Voltage (Vmp), Open-circuit voltage (Voc), Short-circuit current (Isc), Maximum Power Current (Imp), Maximum Power (Pmp), Maximum Efficiency (η) and Fill Factor (FF) – and the optical characteristics: Internal Quantum Efficiency (IQE) and the External Quantum Efficiency (EQE). The electrical characteristics and Figures of Merit of the photovoltaic cells were obtained by means of the following procedures: definition of the optical characteristics of the materials constituting the antireflective layer and the electrode (refractive index), as well as for the constituent material of the substrate, Parameters related to the lifetime of the bearers were defined, as well as to the configuration of the band's energy. By multiphysical models, the V_{OC} value was obtained when the current value at the cathode of the cell was zero. And the I_{SC} was defined when the maximum current value at the cathode. To determine optical characteristics wavelength-related parameters were defined when with solar irradiance of 0.1 W/cm^2. For the whole simulation process, the simulated solar irradiance in the cell was corresponding to 0.1 W/cm^2, as well as the temperature of the solar cell consisted of 25°C (defined as 298.16 K), with an air mass of 1.5 (AM1.5) according to *Standard Test Conditions* (STC).

2.2 The nine cells

2.2.1 Cell 01. It is a cell whose anti-reflective layer and electrode are formed by thin films of SiO_2 and aluminum, respectively. The cell manufacturing process follows the flow of the Figure 1 and has been divided into several steps described below.

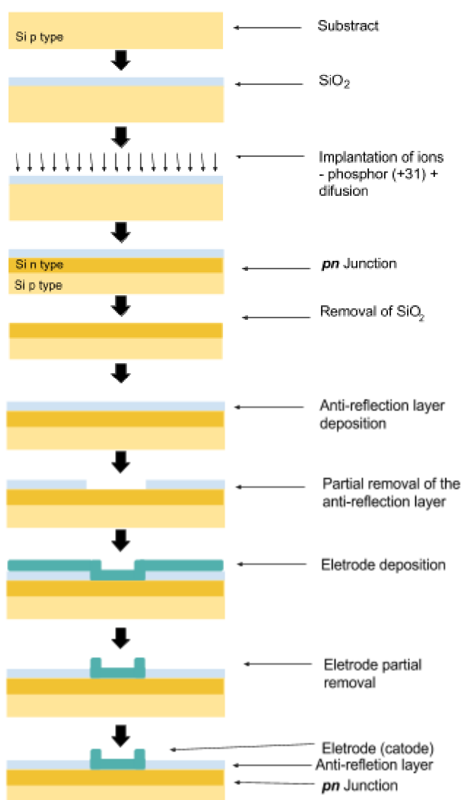

Figure 1: *Flow of the manufacturing process of photovoltaic cells.*

1. Selection of a silicon monocrystalline substrate doped with trivalent (boro, in concentration 10^{14} / cm^3);
2. Definition of the grid to be considered when applying the FEA, according to Figure 2 (for the x axis, between 0 and 40µm, spacings of 1µm^2, while for the y axis, between 0.050 and 0µm, spacing of 0.05µm^2; 0 and 0.25µm, 0.02µm^2; 0.25 and 1µm, 0.1µm^2; 1 and 50µm, 10µm^2).
3. Deposition of a layer of silicon dioxide (SiO_2), 0.05µm of thickness;
4. Implantation of phosphorus ions (with concentration of 10^{15} / cm^3), with energy of 30keV;
5. Process of diffusion of ions, with time of 10 minutes and under temperature of 900ºC;
6. Complete removal of the SiO_2 deposited in step 3;
7. Deposition of the anti-reflective layer, thickness 0.18µm;
8. Partial removal of the anti-reflective layer (4µm in length between 18µm and 22µm);
9. Deposition of aluminum film (electrode) with thickness 0.36µm;
10. Partial removal of the aluminum film for definition of the upper electrode.

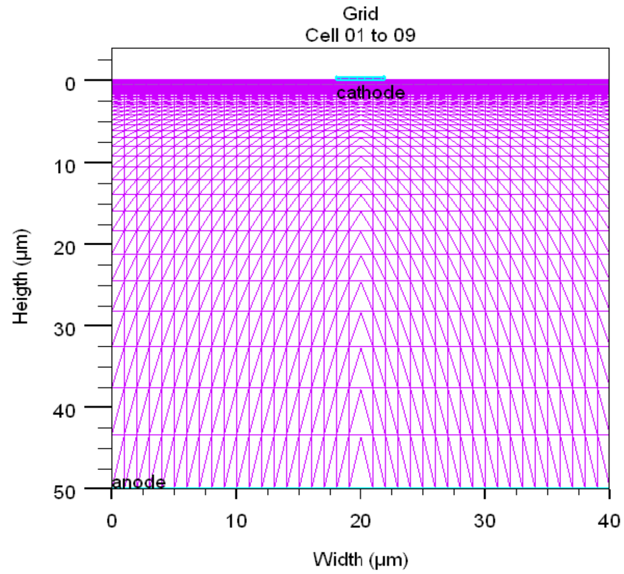

Figure 2: *Grid of the Cell 01 (Equivalent for all cells).*

2.2.2. Cell 02. It is a cell whose anti-reflective layer and electrode are formed by thin films of titanium dioxide (TiO_2) and aluminum, respectively. The manufacturing process is like that of Cell 01. However, in this case, the SiO_2 layer was replaced with a TiO_2 thin film.

2.2.3. Cell 03. It is a cell whose anti-reflective layer and electrode are formed by thin films of Silicon Nitride (Si_3N_4) and aluminum, respectively. The manufacturing process is like that of Cell 01. However, in this situation, the SiO_2 layer was removed and replaced with a thin film of Si_3N_4.

2.2.4. Cell 04. It is a cell whose anti-reflective layer and electrode are formed by thin films of SiO_2 and a transparent conductive oxide (TCO) called tin-doped indium oxide (ITO), respectively. The manufacturing process is like that of Cell 01. However, at Step 9 the aluminum film was replaced by an ITO film.

2.2.5. Cell 05. It is a cell whose anti-reflective layer and electrode are formed by thin films of SiO_2 and a TCO called zinc oxide (ZNO), respectively. The manufacturing process is like that of Cell 01. However, at Step 9 the aluminum film was replaced by a ZNO film.

2.2.6. Cell 06. It is a cell whose anti-reflective layer and electrode are formed by thin films of TiO_2 and ITO, respectively. The manufacturing process is like that of Cell 01. However, in Step 7, instead of using the SiO_2 layer, a thin film of TiO_2 was applied, and at Step 9 the aluminum film was replaced by a film of ITO.

2.2.7. Cell 07. It is a cell whose anti-reflective layer and electrode are formed by thin films of TiO_2 and ZNO, respectively. The manufacturing process is like that of Cell 01. However, in Step 7, instead of using the SiO_2 layer, a thin film of TiO_2 was applied, and at Step 9 the aluminum film was replaced by a film of ZNO.

2.2.8. Cell 08. It is a cell whose anti-reflective layer and electrode are formed by thin films of Si_3N_4 and ITO, respectively. The manufacturing process is like that of Cell 01. However, in Step 7, instead of using the SiO_2 layer, a thin film of Si_3N_4 was applied, and at Step 9 the aluminum film was replaced by a film of ITO.

2.2.9. Cell 09. It is a cell whose anti-reflective layer and electrode are formed by thin films of Si3N4 and ZNO, respectively. The manufacturing process is like that of Cell 01. However, in Step 7, instead of using the SiO2 layer, a thin film of Si3N4 was applied, and at Step 9 the aluminum film was replaced by a film of ZNO.

3 RESULTS AND DISCUSSION

The Table 1 shows the essential Figures of Merit obtained in the nine cells. It is important to include that all Maximum Voltages (Vmp) and all Open-circuit Voltages (Voc) was always, respectively, – 0.4 V and – 0.3 V for all cells. Moreover, the Internal Quantum Efficiency (IQE) remained 98% for all cells. The junction depth was approximately 0.40µm.

Table 1: *Most important Figures of Merit of the nine cells.*

Cell/ Figure of Merit	P_{MP} (W)	EQE (%)	η (%)	FF (%)
01	3.11E-10	69	11.84	75.13
02	3.53E-10	86	13.47	75.85
03	3.6E-10	79	13.63	75.91
04	3.38E-10	75	12.84	75.59
05	3.52E-10	77	13.36	75.80
06	3.82E-10	92	14.51	76.23
07	3.96E-10	94	15.04	76.40
08	3.86E-10	84	14.67	76.28
09	4.00E-10	87	15.21	76.45

3.1 Alteration of the anti-reflective layer

Comparing the first three cells, the third cell, with anti-reflective layer of Si_3N_4, showed better efficiency than others. The Efficiency (η) and Fill Factor (FF) values obtained for Cell 03 were 13.63% and 75.91%, respectively, while the efficiency of the Cell 01 and Cell 02 was, respectively, 11.84% and 13.47% (increase of 1,63%). That is, an efficiency whose value is slightly below the values reported in the literature [3]. However, because of the low difference of the increment that the Cell 02 and 03 shows, comparing with the cell 01 (1.63% and 1.79%, respectively), as well as the best EQE value of the cell 02 [4], comparing the three cells, this is confirm the informations reported in the literature, which affirm the quality of this two materials, comparing with the SiO_2 [5]. In other words, Si_3N_4 and TiO_2 are very good materials for used like antireflective layer.

In addition, the External Quantum Efficiency (EQE) was highest in the Cells 02, 06 and 07, which uses the TiO_2. This proves which, in this criterion, the TiO_2 is better than Si_3N_4. Besides that, the use of the ZnO provided the highest result: 94% in the Cell 07. The Figures 3 and 4 shows the IQE and EQE parameters of the cells 02 and 07.

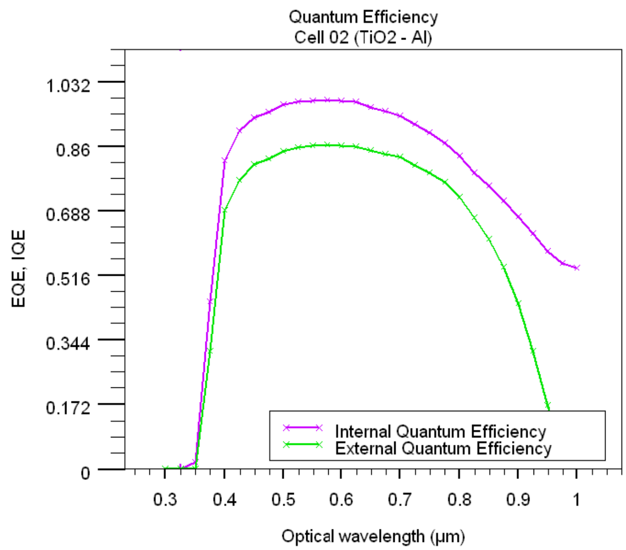

Figure 3: *IQE and EQE of the Cell 02.*

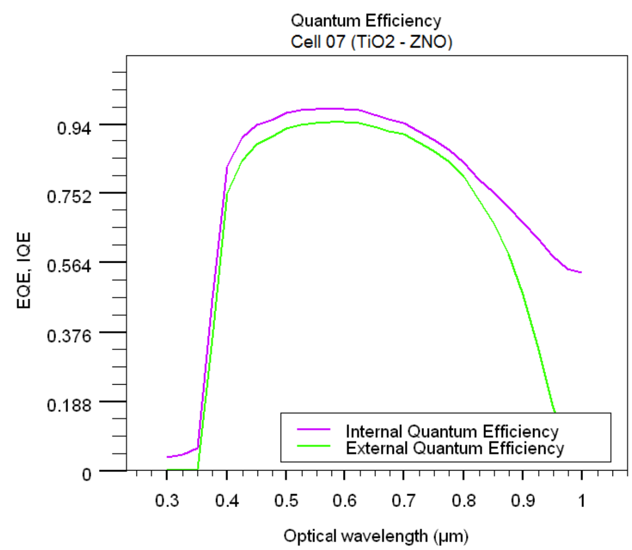

Figure 4: *IQE and EQE of the Cell 07.*

3.2 Alteration of the eletrode

The Efficiency (η) and Fill Factor (FF) values obtained for the Cell 09 were 15.21% and 76.45%, respectively. Therefore, the replacement of the aluminum electrode (cell 03) by the ZnO electrode (Cell 09) caused the efficiency of the cell to increase by 1.58%, proving the best performance of the cell using the "transparent" ZnO electrode, as well as in the cell 08 comparing with the Cell 03, using the ITO, the efficiency was increased 1.04%. The Figure 5 shows the photogeneration in the Cell 01 (first cell with aluminum) and Figure 6 shows right that for the Cell 04 (first cell with TCO electrode). The high photogeneration rates observed in the regions under the electrodes of cells 04, 05, 06, 07, 08 and 09, as well as the improvement observed in the Fill Factor of the cells, confirm the criteria of transparency, refractive index and conductivity of the ITO and ZnO films used [6] [7].

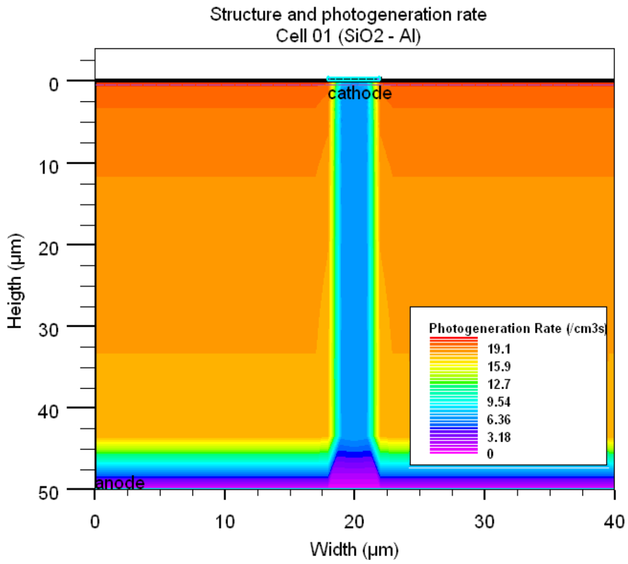

Figure 5: *Photogeneration of the Cell 01.*

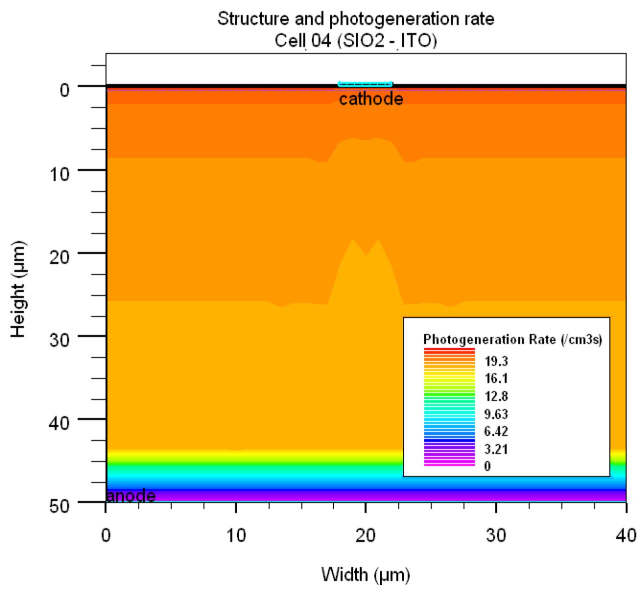

Figure 6: *Photogeneration of the Cell 04.*

4 CONCLUSIONS

With the changes made in the measured photovoltaic cells, it was possible to verify the advantage offered by anti-reflective layers constituted by titanium dioxide (TiO_2) and silicon nitride (Si_3N_4), due to its favorable optical properties (high refraction index and low coefficient of absorption), resulting in considerable improvements in cell yield (cells 02 and 03) as affirmed in the literature [4] [5]. In addition, for each cell mentioned, when the aluminum electrode was replaced by the transparent conductive oxides (TCOs), zinc oxide (ZNO) and tin oxide doped indium oxide (ITO), the improvement of the merit figures of the cells was observed. This is because these oxides are transparent (allow the passage of light) and, at the same time, conductive materials. [6] [7]. Therefore, with the obtained results, is expected to be possible the real manufacturing of, at least, one of the nine cells studied.

A APPENDICE

A.1 Introduction

A.2 Experimental and Computational Details

A.2.1 Photovoltaic cells manufaturing

A.2.2 The nine cells

A.3 Results and Discussion

A.3.1 Alteration of the anti-reflective layer

A.3.2 Alteration of the eletrode

A.4 Conclusions

A.5 References

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